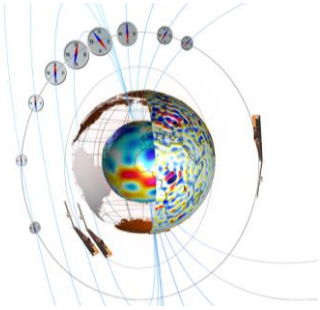

Swarm Level 2 Processing System

Intermediate Validation of Swarm Level 2 Euler Angle Product

SW_OPER_MSW_VALi2C_20131201T000000_20170101T000000_0201

By: DTU

Date: 2017-04-11

Abstract and Conclusion

The processes and tests applied in the intermediate validation of the MSW_EULi2C product

SW_OPER_MSW_EULi2C_20131201T000000_20170101T000000_0201

and the conclusions on the product quality drawn herefrom are described in this document.

This product contains the representation of the estimated Euler angles for the three Swarm satellites ("MSW_EUL" part of product name). The angles are estimated from Swarm and observatory data using the Comprehensive Inversion (CI) scheme within the Swarm Level 2 Processing system ("2C" part of product name). Operational Swarm Level 1b data version 0501, covering the period from 2013-12-01 to 2016-12-31 are used for the model estimation; the product is valid over the same period ("20131201T000000_20170101 T000000" part of product name). This is version 0201 of the product (last part of product name), i.e. same baseline (02) version as the previous CI product release and this is the first, minor version of the product. The format of the product is described in "Product Specification for L2 Products and Auxiliary Products", doc. no. SW-DS-DTU-GS-0001.

The assessment of the SW_OPER_MSW_EULi2C_20131201T000000_20170101T000000_0201 product shows good stability and agreement with existing values of the Euler angles.

The DTU SIL's opinion is that the MSW_EULi2C product is validated and is therefore suitable for release.

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Abbreviations

Acronym	*Description*
AR-2	Acceptance Review 2
CI	Comprehensive Inversion
L2PS	Level 2 Processing System
MMA	Magnetic Magnethospheric field
PDGS	Payload Data Ground Segment
SHA	Spherical Harmonic Analysis
SIL	Scientist in the Loop
STR	Star Tracker
TDS	Test Data Set
VAL	Validation
VFM	Vector Field Magnetometer

References

[Sabaka, GRL, 2016] *Extracting Ocean-Generated Tidal Magnetic Signals from Swarm Data through Satellite Gradiometry*; Sabaka, Terence J. ; Tyler, Robert H. ; Olsen, Nils in journal: Geophysical Research Letters (ISSN: 0094-8276), doi: 10.1002/2016GL068180, 2016

1 Intermediate Validation Report of MSW_EULi2C

1.1 Input data products

The following input data products were used for the estimation of the MSW_EULi2C Euler angles.

Products	Type	Period	Comment
SW_OPER_Q3D_CI_i2__00000000T000000_99999999T999999_0101	Q-matrix of Earth's (1-D mantle + oceans)	-	Used for computing induced part of ionospheric field
SW_OPER_AUX_OBS_2__20130101T000000_20131231T235959_0109 SW_OPER_AUX_OBS_2__20140101T000000_20141231T235959_0109 SW_OPER_AUX_OBS_2__20150101T000000_20151231T235959_0109 SW_OPER_AUX_OBS_2__20160101T000000_20161231T235959_0109	Observatory hourly mean values	2013-12-01 – 2016-10-31	A total of 143 observatories are included
SW_OPER_AUX_DST_2__19980101T013000_20170103T233000_0001 SW_OPER_AUX_F10_2__19980101T000000_20170101T000000_0001 SW_OPER_AUX_KP__2__19990101T023000_20161215T223000_0001	Indices	As indicated by the file names	
SW_OPER_MAGA_LR_1B_*yyyymmdd*Th1m1s1_*yyyymmdd*Th2m2s2_0501 SW_OPER_MAGB_LR_1B_*yyyymmdd*Th1m1s1_*yyyymmdd*Th2m2s2_0501 SW_OPER_MAGC_LR_1B_*yyyymmdd*Th1m1s1_*yyyymmdd*Th2m2s2_0501	Swarm magnetic data, 1 Hz	2013-12-01 - 20165-12-31	Decimated to 15 second sampling

Table 1-1: Input data products

1.2 Model Parameterization and Data Selection

See Section 2.1.

1.3 Output Products

The products of this validation report are:

Swarm Level 2 Euler angle Product:

SW_OPER_MSW_EULi2C_20131201T000000_20170101T000000_0201

Swarm Level 2 Intermediate Validation Product:

SW_OPER_MSW_VALi2C_20131201T000000_20170101T000000_0201

1.4 Validation Results

The tests were conducted between 2017-02-14 and 2017-03-02

The following tests have been applied to the Euler angles product.

1.4.1 Variation of Euler Angles

Figure 1-1 below shows the variation of the estimated Euler angles throughout the period covered. The Euler representation given in the MSW_EULi2C product is of the 1-2-3 type (rotation about *x*-, *y*-, and *z*-axes in that order), however the representation used in Figure 1-1 (2-3-1) yields a more visually true impression of the Euler angle variations. The observed variations in the γ angles are believed to be aliasing of magnetic fields of far from Earth magnetospheric currents rather than physical changes of the Euler angles.

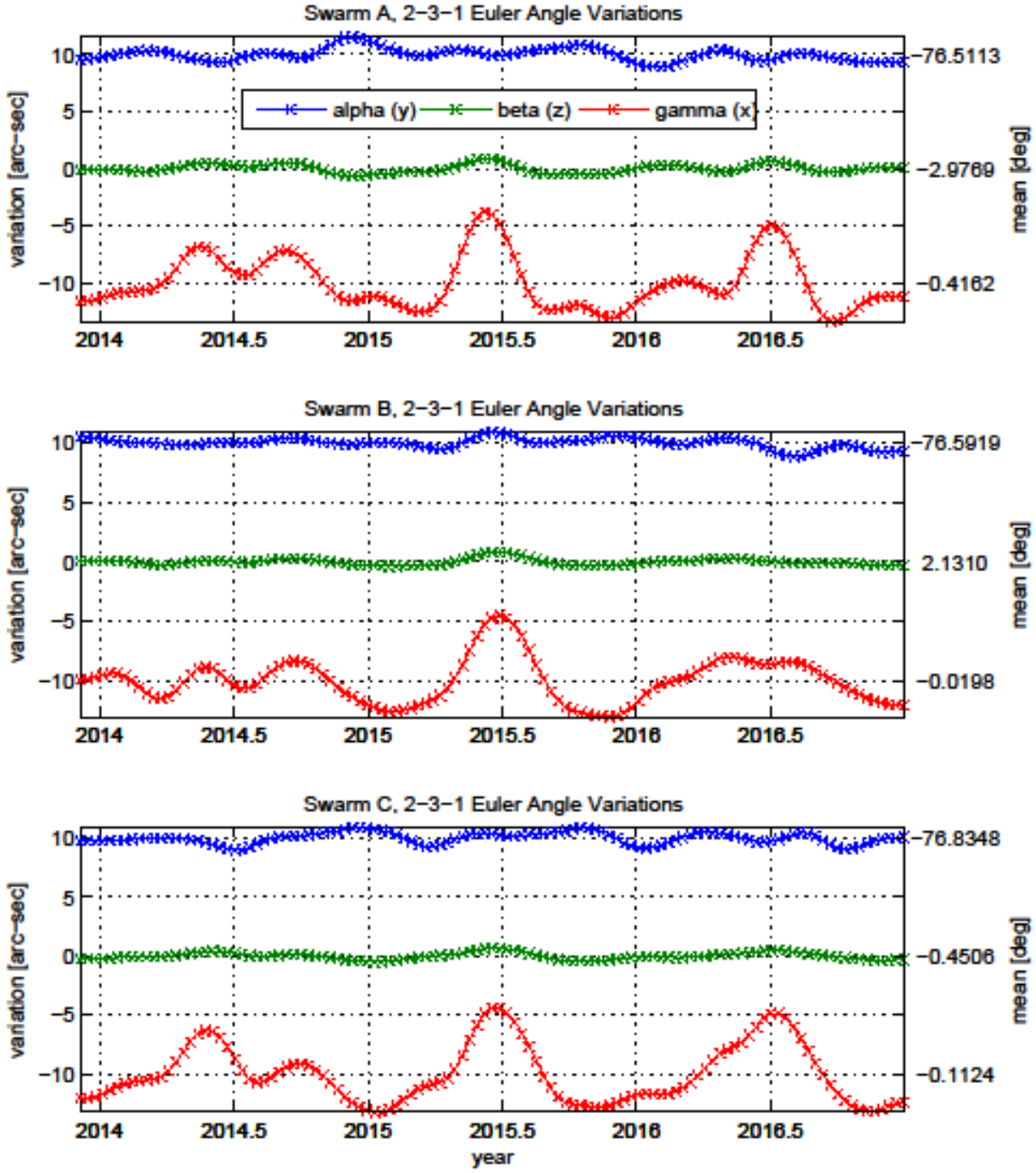

Figure 1-1: Variations of Estimated Euler Angles

1.4.2 Comparison with Current Euler Angle Values

Table 1-2 below lists the mean values of the estimated Euler angles from Figure 1-1 together with the corresponding values from the Level 1b processing Calibration and Characterisation Database (CCDB) and shows very good agreement.

Swarm	**Angle**	**Estimated** [deg]	**CCDB (“*Current*”)** [deg]	**Difference** [arc-sec]
A	Alpha	-76.5113	-76.5114	0.16
	Beta	-2.9769	-2.9774	1.78
	Gamma	-0.4162	-0.4157	-1.62
B	Alpha	-76.5919	-76.5920	0.49
	Beta	2.1310	2.1318	0.34
	Gamma	-0.0198	-0.0192	-2.45
C	Alpha	-76.8348	-76.8347	-0.38
	Beta	-0.4506	-0.4510	1.34
	Gamma	-0.1124	-0.1120	-1.44

Table 1-2: Comparison between MSW_EULi2C and CCDB values

1.4.3 Data Statistics

The statistics of the measurement data obtained by the CI modelling is given in Table 1-3 below. Grey cells indicate data from night-side, white cells indicate data from sunlit regions. Crossed cells indicate data which are not used in the inversion process. “Field” indicate the pure vector and scalar measurements, whereas “NS diff” and “EW diff” indicate the North-South (along-track) respectively East-West differences. The standard deviations (of the residuals between the observations and the estimated model) of the differences are quite impressive; the standard deviations of the direct field measurements from the satellites are also quite excellent whereas the ground observatories show slightly higher residuals than previously recorded. Note also the expected similarity between Swarm A and C (side-by-side flying pair) and North-South differences for all three satellites. Swarm B shows slightly higher residuals in the Field components at low and mid latitudes and slightly lower residuals at high latitudes likely due to its higher altitude.

Swarm/ Obs.		Geomagnetic quasi-dipole latitude											
		Low, ≤ 10°				Mid,]10°..55°]				High, > 55°			
		Standard deviations of data residuals, Huber weighted, [nT]											
		$\sigma(B_r)$	$\sigma(B_\theta)$	$\sigma(B_\varphi)$	$\sigma(F)$	$\sigma(B_r)$	$\sigma(B_\theta)$	$\sigma(B_\varphi)$	$\sigma(F)$	$\sigma(B_r)$	$\sigma(B_\theta)$	$\sigma(B_\varphi)$	$\sigma(F)$
A	Field	1.77	3.30	1.98	3.21	2.73	3.62	2.86	2.06				5.97
	NS diff	0.38	0.18	0.37	0.19	0.26	0.33	0.39	0.20				1.84
		1.30	0.98	1.20	0.85	0.61	0.72	1.27	0.33				2.59

Swarm/ Obs.		Geomagnetic quasi-dipole latitude											
		Low, ≤ 10°				Mid,]10°..55°]				High, > 55°			
		Standard deviations of data residuals, Huber weighted, [nT]											
		$\sigma(B_r)$	$\sigma(B_\theta)$	$\sigma(B_\varphi)$	$\sigma(F)$	$\sigma(B_r)$	$\sigma(B_\theta)$	$\sigma(B_\varphi)$	$\sigma(F)$	$\sigma(B_r)$	$\sigma(B_\theta)$	$\sigma(B_\varphi)$	$\sigma(F)$
B	Field	1.95	4.07	2.84	4.00	3.14	4.48	3.77	2.71				5.78
	NS diff	0.38	0.18	0.36	0.19	0.26	0.34	0.40	0.22				1.61
		1.10	0.79	1.06	0.66	0.58	0.68	1.21	0.31				2.28
C	Field	1.78	3.33	2.02	3.27	2.79	3.66	2.83	2.11				5.98
	NS diff	0.40	0.19	0.38	0.19	0.28	0.35	0.41	0.21				1.85
		1.30	0.98	1.21	0.89	0.63	0.74	1.29	0.33				2.59
A-C	EW diff	0.83	0.36	0.99	0.29	0.43	0.49	0.94	0.28				0.62
		2.10	0.78	2.52	0.55	0.96	1.10	1.64	0.44				0.75
Magnetic observatories		5.70	5.32	4.43	4.81	5.55	5.14	4.44	4.79	16.82	14.01	10.53	17.61
		12.38	13.02	10.88	11.79	8.32	8.93	10.15	8.39	23.42	22.58	16.94	26.04

Table 1-3: Observation Statistics

1.5 Criteria

Table 1-4 below summarizes the criteria used to check the validity of the MSW_EULi2C product:

Input	Test	Criteria	Pass?
Observations	Residual statistics	Standard deviation of quiet time vector data below 7 nT.	Ok
Current Euler Angles	Comparison with CCDB values	CI model agrees with current values	Ok

Table 1-4: Validation criteria

2 Additional Information

2.1 Model Configuration and Data Selection Parameters

The MSW_EULi2C product is obtained as a comprehensive co-estimation of the core, lithosphere, ionosphere, and magnetosphere field contributions including induced contributions based on quite time data similar to the method described in [Sabaka, GRL, 2016]. The complete model configuration used is given in Table 2-1 below; the MSW_EULi2C product is the green part:

Model Part	**Maximum Degree/Order**	**Temporal Characteristics**	**Comment**
Core	16/16	Order 5 B-spline with knots every 6 months	Damping of the mean-square, second and third time derivative of B_r at the core-mantle boundary (at 3480 km radius).
Lithosphere	90/90	Static	Degree 17-90 purely determined by North-South differences from all satellites and East-West differences of lower pair satellite (A and C). Damping of B_r at the poles to reduce effect of lack of data at the poles ("*polar gap*")
Ionosphere	45/5 (dipole coordinates)	Annual, semi-annual, 24-, 12-, 8- and 6- hours periodicity	Spherical harmonic expansion in quasi-dipole (QD) frame, underlying dipole SH $n_{max} = 60$, $m_{max} = 12$. Scaling by 3-months averages of F10.7 plus induction via a priori 3-D conductivity model ("1-D + oceans") and infinite conductor at depth. Damping of: 1. Mean-square current density J in the E-region within the nightside sector (magnetic local times 21:00 through 05:00) 2. Mean-square of the surface Laplacian of J multiplied by a factor of $\sin^8(2\theta)$ over all local times, where θ is co-latitude.

Model Part	Maximum Degree/Order	Temporal Characteristics	Comment
Magnetosphere, external	3/1	One hour bins	
Magnetosphere, induced	3/3	One hour bins	
M2 Tidal	36/36	Periodicity: 12.42060122 hr, phase fixed with respect to 00:00:00, 1999 January 1 GMT	
Euler Angles	N/A	Ten days bins	Regularised to prevent cross-talk with time-varying parts of the magnetic field model

Table 2-1: Model Configuration

The data selection criteria are:

- Coarse agreement with CHAOS-6 field model: $\Delta B_c \leq 500$ nT for all components $c=r,\vartheta,\varphi$, and $\Delta F \leq 100$ nT.
- $Kp \leq 3^0$
- Time-derivative of Dst: $|dDst/dt| \leq 3$ nT/hour
- 15 second satellite sampling period
- Core and tidal fields determined from night-side data only, i.e. with Sun $\geq 10°$ below the horizon

2.2 Comments from Scientists in the Loop

2.2.1 Derivation of Model

The final Comprehensive Inversion model for the first three years of Swarm data shows good agreement with alternative models.

2.2.2 Conclusion

The estimated angles are assessed to be of good quality with very good agreement with the Euler angles currently applied to the Swarm Level 1b data.